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RESEARCH MEMORANDUM

INVESTIGATION OF THE AIR-FLOW-REGULATION CHARACTERISTICS

OF A TRANSLATING-SPIKE INLET WITH TWO OBLIQUE

SHOCKS FROM MACH 1.6 TO 2.0

By J. C. Nettles

Lewis Flight Propulsion Laboratory
Cleveland, Ohio

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RESEARCH MEMORANDUM

INVESTIGATION OF THE AIR-FLOW-REGULATION CHARACTERISTICS OF A TRANSLATING-SPIKE INLET WITH TWO OBLIQUE SHOCKS FROM MACH 1.6 TO 2.0

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SUMMARY

The air-flow regulation and pressure recovery of a translating-cone inlet with a 15° initial conical half-angle and a 10° additional compression was investigated for a range of spike positions at Mach numbers of 0.6 and 1.6 to 2.0 at zero angle of attack. Performance at the 5° angle of attack was determined at a Mach number of 2.0. The pressure recovery of the two-shock inlet was essentially the same as the pressure recovery with a single 25° half-angle cone. For a given spike position the variation of critical equivalent air flow was small for a Mach number range of 1.6 to 2.0. Matching the inlet to a turbojet engine indicated that the required translation for the two-shock cone was greater than for a 25° cone.

The subcritical stability of the two-shock inlet was improved over that of the single-shock inlet. For spike positions that placed the first oblique shock inside the cowl lip, the two-shock inlet displayed a pronounced hysteresis of the minimum stable point, which was not characteristic of the single-shock inlet.

INTRODUCTION

Regulation of the critical air flow can be achieved by translating a 25° half-angle cone with a cowl designed for no internal contraction (refs. 1 to 3). For this type of inlet the conical-shock angle defines a spike position that will allow a stream tube equal to the cowl area to enter the diffuser. The variation of the capture stream tube at critical air flow with spike position can be determined from charts in reference 4. Tests are required for this type of inlet to determine the pressure recovery.

If two-shock compression is employed, the condition of the flow field behind the first conical shock hinders the estimation of the shape and angular movement of the second shock. As a consequence, the variation of critical air flow with spike position and flight Mach number can not be readily determined. It is also usually desirable from the standpoint of pressure recovery to operate the inlet so that the second shock does not fall inside the cowl lip.

In order to obtain data on the air-flow-regulation characteristics of a translating-cone two-shock inlet, an extension having a 15° half-angle was added to the 25° half-angle inlet (ref. 2). The investigation was conducted in the Lewis 8- by 6-foot tunnel from Mach 1.6 to 2.0.

APPARATUS AND PROCEDURE

The general layout of the model is shown in figure 1. The model support strut was so arranged that a 5° angle of attack could be obtained by rotating the entire assembly relative to the tunnel ceiling. Figure 2 presents the variation of the flow-area ratio of the subsonic diffuser in terms of the initial hydraulic diameter for the foremost and rearmost spike positions. The area ratio for a 3° half-angle conical diffuser is shown for comparison (fig. 2). The particular cowl used in these tests was contoured to provide approximately 1 hydraulic diameter of essentially constant flow area at the subsonic diffuser inlet.

The flow through the diffuser was controlled by a translating plug at the exit. Air flow was calculated from the exit area and an average static pressure which was measured at a station ahead of the plug. Pressure recovery was determined as an average of the total pressure measured at a station approximately $3\frac{1}{2}$ cowl diameters downstream of the cowl entrance.

Pulsing was detected by observation of a schlieren apparatus and pressure transducers connected to an oscilloscope.

The juncture between the 15° cone and the 25° cone was selected to cause intersection of both oblique shocks at the cowl lip at a free-stream Mach number of 2. The curvature of the second shock was approximated. This method was based upon a linear interpolation of the Mach number with the ray angle from the cone surface to the first-oblique shock and upon the assumption that the deflection through the second shock was constant (ref. 5).

RESULTS AND DISCUSSION

The variation of pressure recovery with equivalent air flow is presented in figure 3 for various Mach numbers and spike positions. Equivalent air flow was based on the cowl capture area and is related to the mass-flow ratio by the expression

$$w\sqrt{\theta_2}/A_i\delta_2 = 49.4(A^*/A_0)(m_2/m_0)\left(\frac{1}{P_2/P_0}\right)$$

Contours of the mass-flow ratio, m_2/m_0 are shown for reference in figure 3. Spike position is given as M_D, which is the Mach number at which the shock from the 15° half-angle cone would intersect the cowl lip with a particular spike position. The variation in M_D from 1.87 to 2.15 for a 15° cone is equivalent on a linear translation basis to a variation in M_D from 1.8 to 2.2 for a 25° cone.

The method used for determining the juncture between the 15° and 25° cones did not fully compensate for the curvature of the second shock. As a consequence, when operating at $M_0 = 2.0$ with the spike at its design position $M_D = 2$, the shock fell from the second conical surface inside the cowl lip. Observation of the schlieren indicated that it was necessary to extend the spike to a position of $M_D = 2.09$ in order to make the second shock intersect the cowl lip. For this spike position the air flow was 96 percent of theoretical maximum at the critical point, and the pressure recovery was 90 percent.

In general, the pressure-recovery performance of the two-shock configuration was the same as that of the single shock. The greatest significant difference occurred for the forward spike position at a Mach number of 2.0, where the peak pressure recovery was 0.91, which compares with 0.895 for the 25° cone. Separation of the flow across the spike juncture did not occur on this model.

Operation of the inlet at an angle of attack of 5° and at a Mach number of 2.0 indicated a small decrease in both the critical air flow and pressure recovery and virtually no subcritical stability range. An approximate calculation indicates that the 5° angle of attack was sufficient to cause shock-induced separation on the upper surface of the second cone according to the criteria of reference 6. This separation may account for the loss of stable flow range.

The performance of the inlet at a Mach number of 0.6 is presented in figure 4 for the limit of spike travel in the fore and aft directions. This performance was essentially the same as that for the 25° spike inlet of reference 2. Extrapolation of the performance to air flows higher than the tested values was made by the methods of reference 7.

The variation with Mach number of critical air flow and pressure recovery for various spike positions is shown in figure 5. The equivalent air flow had a tendency to decrease with increasing Mach number; however, for the Mach range tested the change in air flow was small for any given spike position. The variation in air flow for the 25° spike inlet of reference 2 is shown for comparison (fig. 5). In addition, the air-flow characteristic of a high Mach number turbojet engine utilizing a transonic compressor is shown to illustrate the air-flow regulation range required of an inlet. The engine was arbitrarily matched to the inlet at a free-stream Mach number of 2 with the $M_D = 2.15$ spike position, this being as representative of a high Mach number practice as could be obtained with the present data. It can be seen from the slopes of the various characteristics that the two-shock inlet would require further translation of the spike than the single-shock inlet in order to match the engine over the Mach number range. This particular engine would have constant equivalent air flow for Mach numbers below 1.6, and reference to figure 4 indicates that the inlet with the spike in the retracted position would deliver the required air flow at a free-stream Mach number of 0.6 with a pressure recovery of 95 percent. The supersonic pressure recovery for the engine matched condition varies from 90.5 to 94 percent at the respective free-stream Mach numbers of 2 and 1.6.

The variation of minimum stable subcritical air flow for various Mach numbers and spike positions is shown in figures 6 and 7. A study made of the curves in figures 6 and 7 and of the data of reference 2 indicates that, in general, the addition of the second shock to the supersonic compression system improved the subcritical stability for all spike positions for which M_D is greater than M_O.

When the spike position, M_D, was less than M_O (which places the conical shock inside of the cowl lip), there were large increases in the apparent subcritical mass-flow regulation without the onset of buzz. It was a characteristic of these spike positions, however, that once buzz had started it was necessary to increase the flow almost to the critical value in order to stop the pulsation. Because of this phenomena, there is some question as to the usefulness of this indicated stable range. As the terminal shock approached the spike juncture, buzz occurrence was correlated with the separation of flow on the 15° spike surface.

SUMMARY OF RESULTS

The experimental performance of a two-oblique-shock inlet having a 15° initial-cone half-angle followed by an additional conical compression of 10° is as follows for Mach numbers of 0.6 and 1.6 to 2.0:

1. At critical air flow and a free-stream Mach number of 2 the pressure recovery was essentially the same as with a single 25° half-angle cone. The most significant difference occurred for the forward spike position where the peak pressure recovery was 0.91, which compares with 0.895 for the 25° cone.

2. The variation in equivalent air flow at critical operation was small for a given spike position over the Mach number range of 2.0 to 1.6. Matching the inlet to a hypothetical high-performance turbojet engine indicated that the linear travel of the two-shock cone was greater for matching than would be required by the 25° cone.

3. The subcritical stability of the two-shock inlet was improved over that of the original single-shock configuration for all spike positions that placed the conical shock ahead of the cowl lip. For spike positions which placed the conical shock inside the cowl lip, the performance was similar to the single-shock inlet with large ranges of subcritical stability. However, once buzz started in these later shock positions, it was necessary to increase the flow to nearly the critical value before buzz would cease.

4. Operating the model at an angle of attack of 5° resulted in a complete loss of subcritical stability but only a small reduction in critical air flow and pressure recovery.

Lewis Flight Propulsion Laboratory
National Advisory Committee for Aeronautics
Cleveland, Ohio, April 24, 1956

APPENDIX - SYMBOLS

The following symbols are used in this report:

A flow area, sq ft

A_i cowl-inlet capture area

A^*/A_0 isentropic area ratio, ratio of area at Mach number 1 to free-stream area

D_e hydraulic diameter at cowl inlet, $4A_1$/wetted perimeter

M Mach number

M_D Mach number at which conical shock intersects cowl lip

m mass flow, slugs/sec

P total pressure, lb/sq ft abs

$\bar{P}$ area weighted total-pressure average

w air flow, lb/sec

δ ratio of pressure to NACA standard sea-level absolute pressure

θ ratio of total temperature to NACA standard sea-level absolute temperature

Subscripts:

x axial station

0 free stream

1 cowl inlet

2 diffuser discharge

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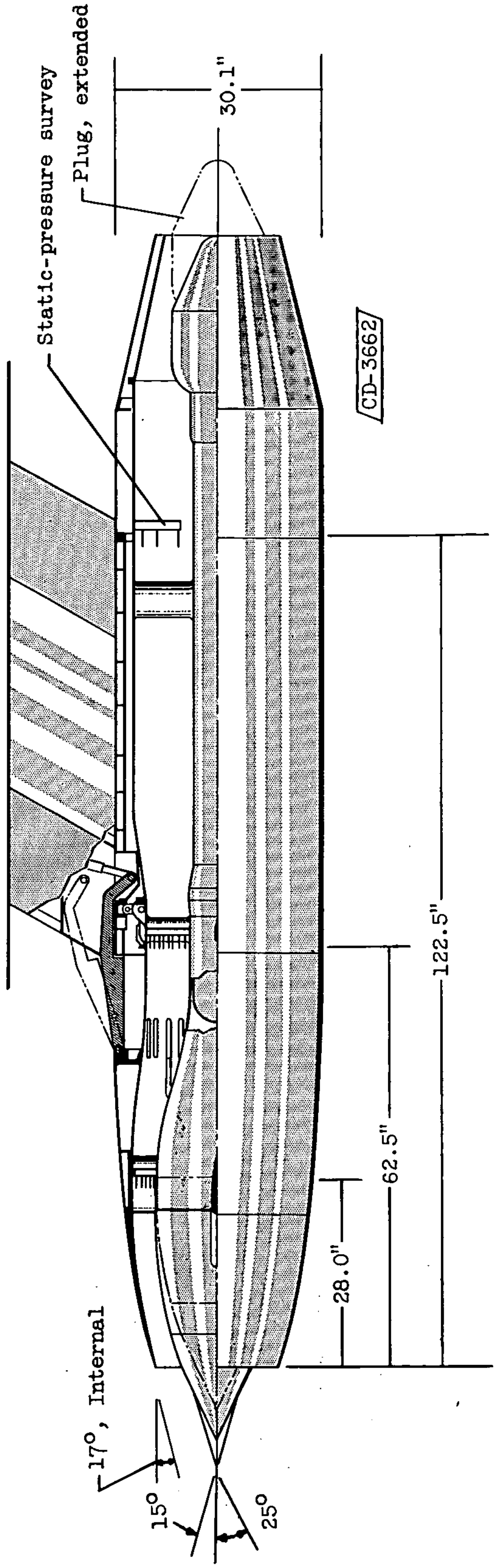

Figure 1. - Detail of model installation.

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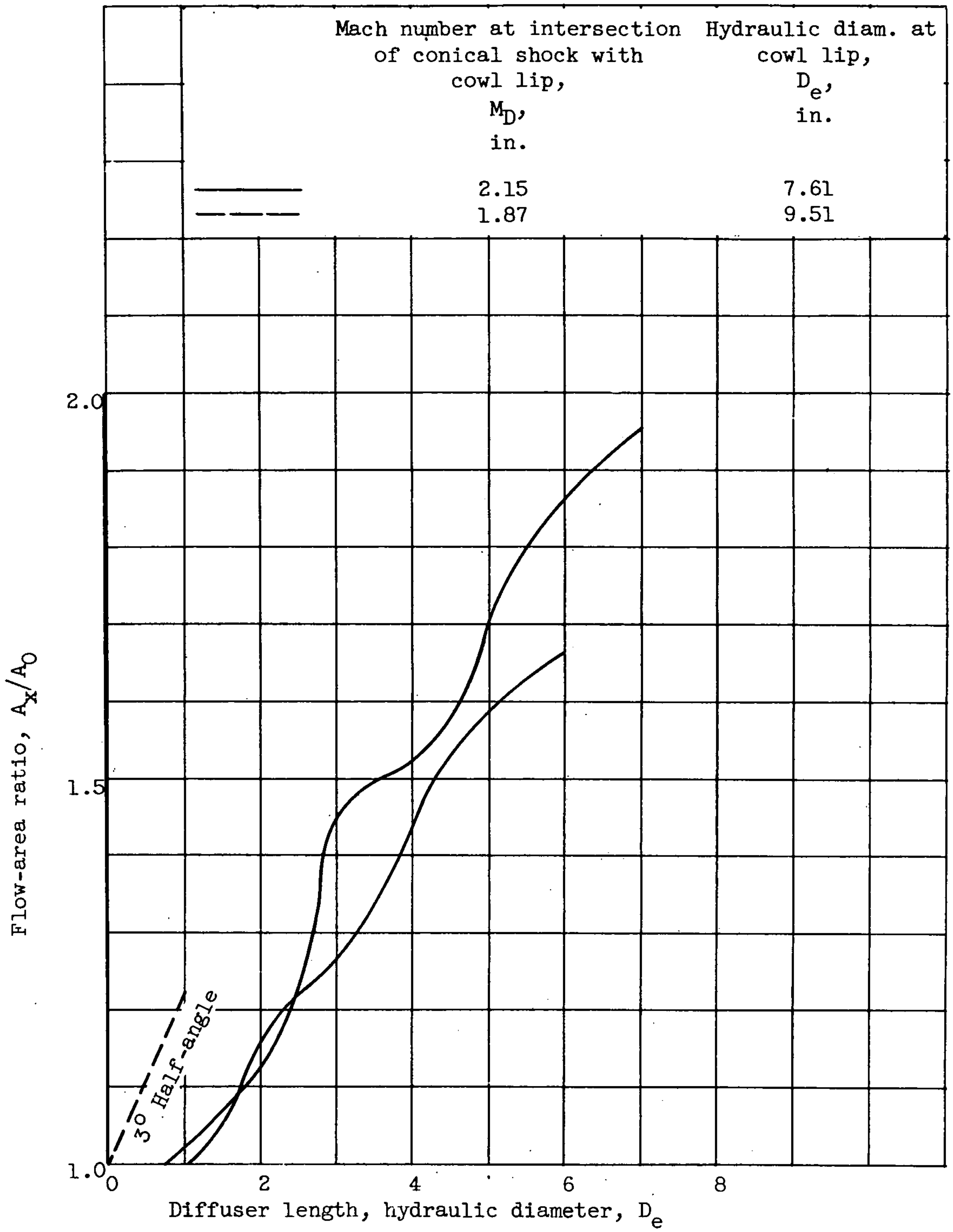
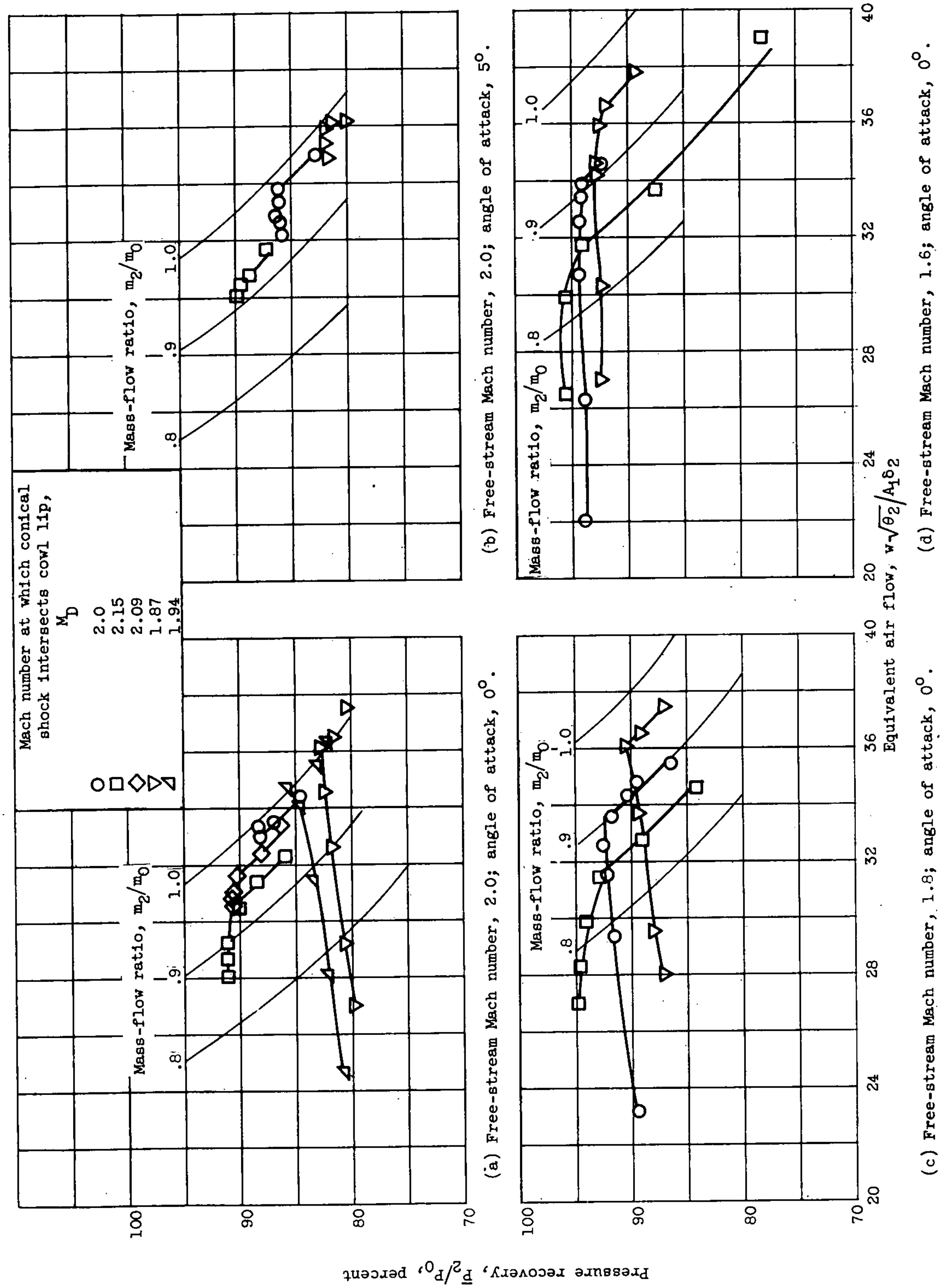


Figure 2. - Variation of flow area for limits of spike travel.



(a) Free-stream Mach number, 2.0; angle of attack, 0°.

(b) Free-stream Mach number, 2.0; angle of attack, 5°.

(c) Free-stream Mach number, 1.8; angle of attack, 0°.

(d) Free-stream Mach number, 1.6; angle of attack, 0°.

Figure 3. - Performance of $15^{\circ}+10^{\circ}$ translating-spike inlet.

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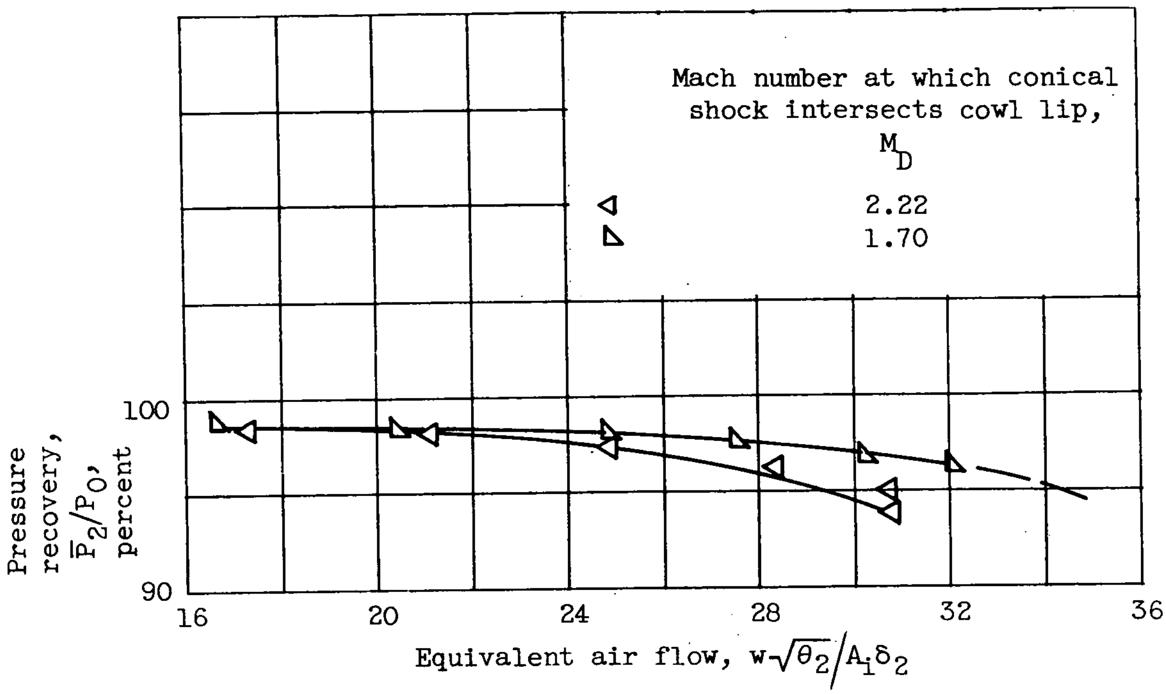

Figure 4. - Performance of 15°+10° translating-spike inlet. Free-stream Mach number, 0.6; angle of attack, 0°.

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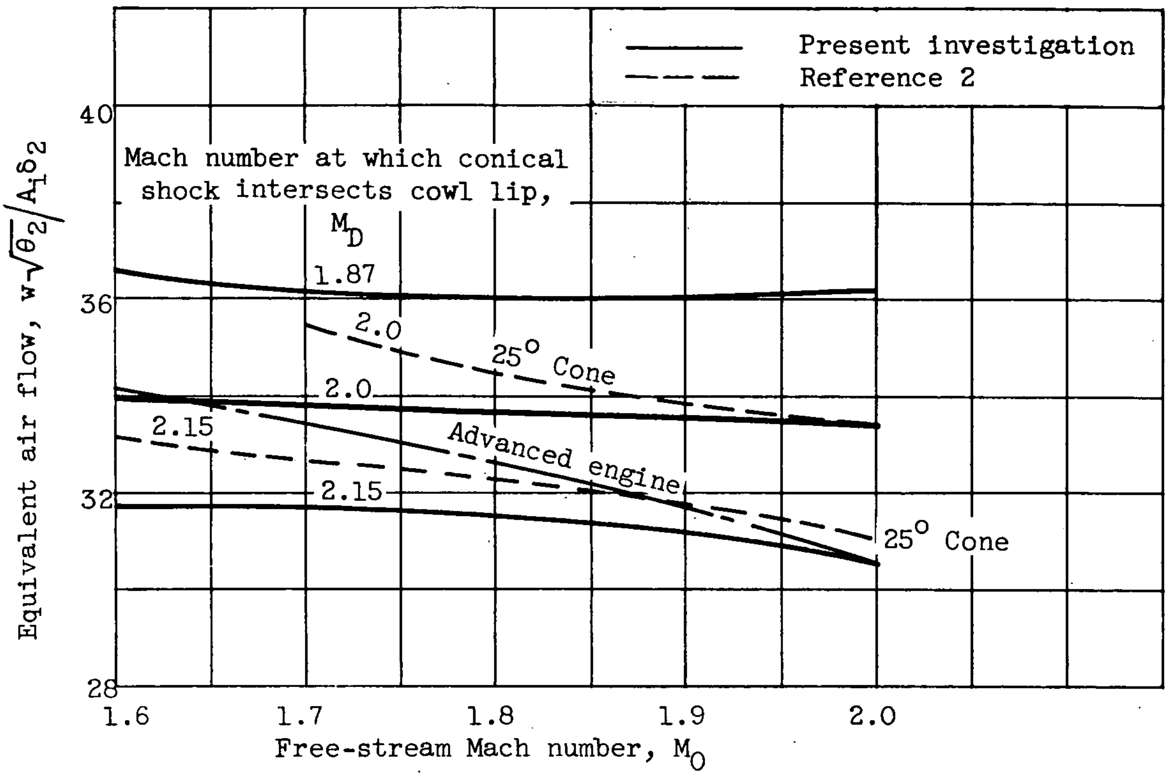

(a) Critical air flow.

Figure 5. - Performance of translating-spike inlet at critical air flow.

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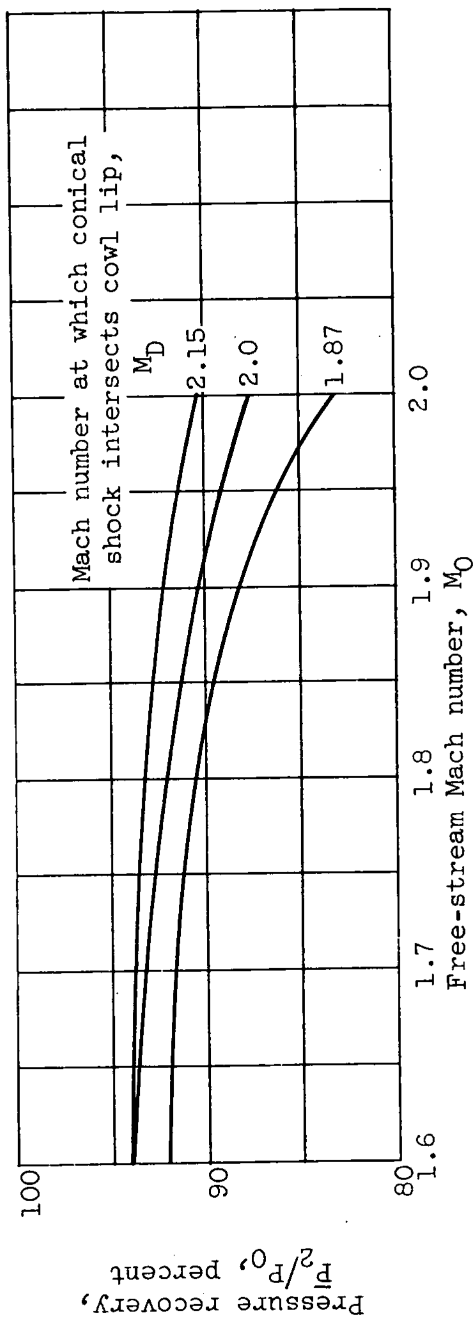

(b) Critical pressure recovery.

Figure 5. - Concluded. Performance of translating-spike inlet at critical air flow.

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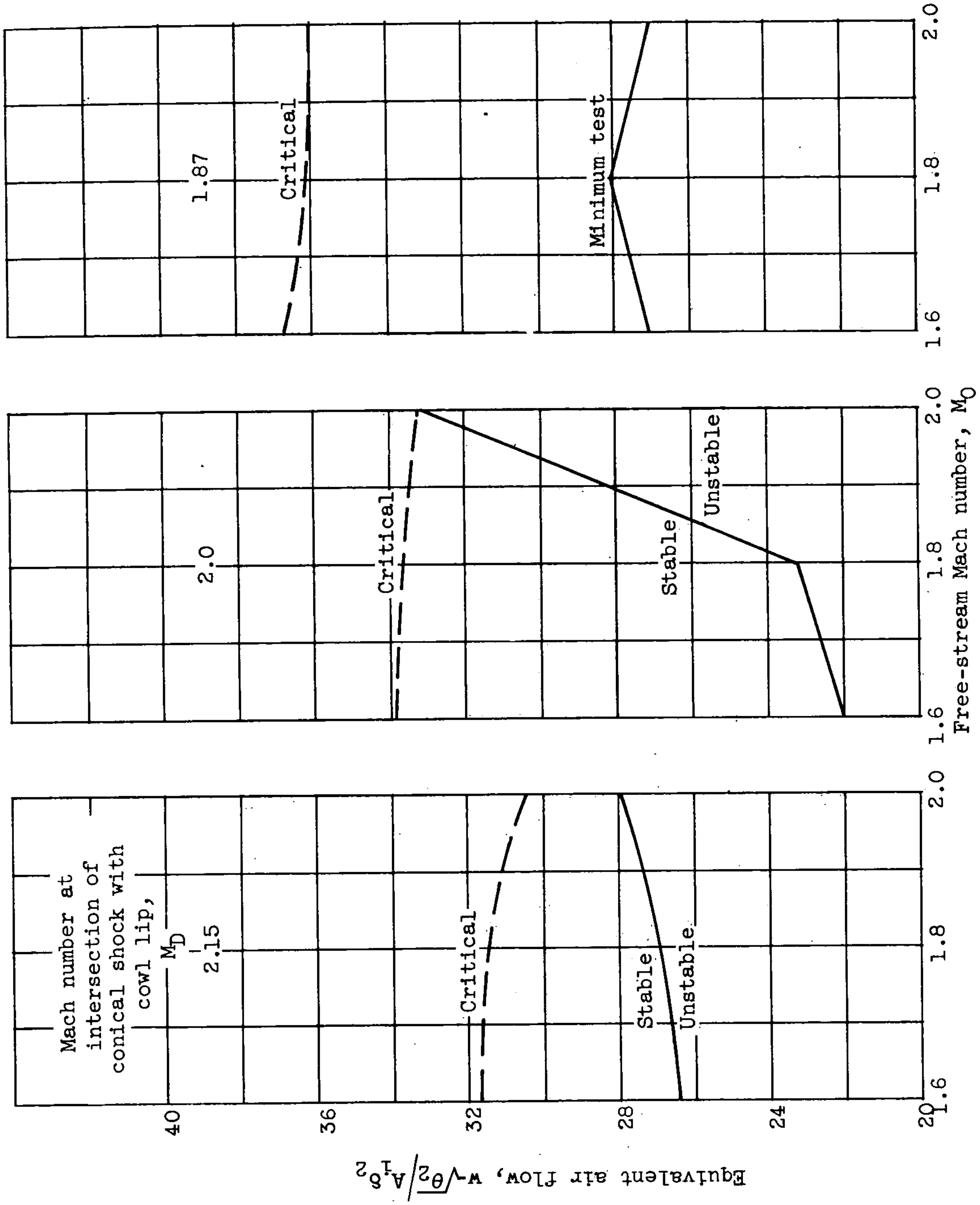

Figure 6. - Stable air-flow range for various spike positions.

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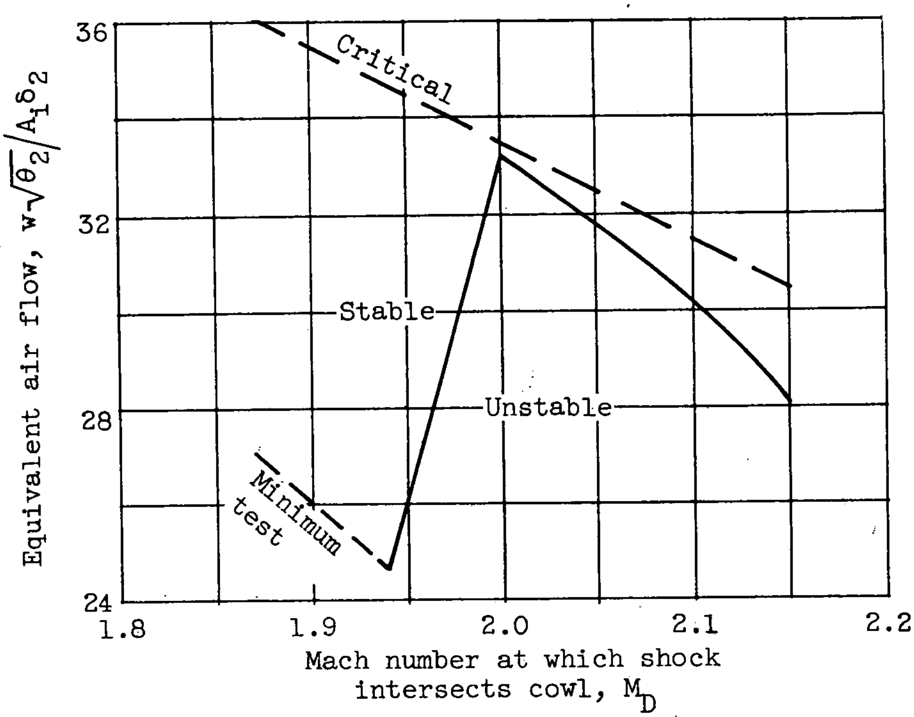

Figure 7. - Effect of spike position on stable air flow. Free-stream Mach number, 2.0.